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Updated ENDL99 Cross Sections for U(n,γ) and U(n,f)

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U.S. Department of Energy
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DISCLAIMER

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Abstract

In this note, we describe the first of two updates to the uranium isoptopes in Livermore's Evaluated Neutron Data Library, ENDL99. Here, we concentrate on improving the (n,f) and (n,γ) evaluations for a limited set of uranium isotopes. The first improvement consisted of creating an evaluation for ^{232}U using a combination of fission and capture cross sections from the JENDL-3.2 database and the outgoing particle distributions from the exiting ENDL99 ^{234}U evaluation. The second improvement consisted of updating existing (n,f) and (n,γ) evaluations for uranium isotopes with A=233-238. These improvements are particularly apparent in the neutron resonance region as ENDL99 often contains gross averages over the resonances. We have propagated these updates into various Livermore application libraries.

1 INTRODUCTION

DNT has requested re-evaluations of the U(n,γ) and U(n,f) cross sections and uncertainties for uranium isotopes with A=231-240 from thermal energies to several MeV. ENDL99, Livermore's Evaluated Neutron Data Library [1], does not contain all of the isotopes of interest and the evaluations contained in it are often inaccurate or contain only averages of the cross sections over unacceptably large ranges of energy. These inaccuracies are most problematic in the neutron resonance region. Many of the required evaluations may be obtained from other databases, such as ENDF/B-VI [2] or JENDL-3.2 [3]. While several isotopes are well studied and have excellent evaluations (e.g. ^{233}U, ^{235}U, and ^{238}U), several of the required isotopes have no evaluations (e.g. ^{231}U, ^{239}U and ^{240}U) or have poorly determined evaluations (e.g. ^{237}U).

It is insufficient to just insert the new evaluations into ENDL99. The changes to ENDL99 must be propagated into data access software libraries such as `ndf`, `mcf` or `tart` for use in various applications. The format for storing the data in these libraries depends on the specific application and typically is either pointwise (e.g. for a Monte-Carlo calculation) or in energy groups (e.g. in a deterministic calculation). In a group calculation, the computation time increases with the number of groups. On the other hand, if one needs greater accuracy then one must to increase the number of groups. This speed vs. accuracy trade-off decision is best left to the user of the data as only they understand their particular computational needs. In many cases, the creators of ENDL99 made this decision already, replacing the resonance structure with an energy average of the cross section. We would like to move this accuracy vs. computational speed decision back into the hands of the user by including a better representation of the U(n,γ) and U(n,f) cross sections in ENDL99.

Because of the need for some level of expediency, we decided to update the ENDL99 evaluations in two stages. In the first stage, we determine the "best" (n,f) and (n,γ) cross section evaluations from existing nuclear reaction databases. We then compare these cross sections to what is already in ENDL99 and update ENDL99 accordingly. We consider the following evaluated nuclear libraries: ENDF/B-VI [2], JENDL-3.2 [3], JEF-2.2 [4], BROND-2.2 [5], and CENDL-2 [6]. In the second stage, we will perform evaluations of the reactions not covered in existing databases and attempt to assign uncertainties to all of the evaluations. These new evaluations will necessarily be simplistic since there is not much data to constrain these evaluations.

We now outline this note. First, we will survey the existing evaluations and compare them to what is in Livermore's ENDL99 database. This will allow us to make recommendations on which evaluations to keep in ENDL99 or to adopt from other databases. Second, we will outline how we adapted the existing ENDL99 database and the application libraries to use these improved evaluations. Next, we will outline our proposed strategies for evaluating the U(n,γ) and U(n,f) cross sections for several under-studied isotopes. Following this, we conclude. Finally, there is an appendix in which we briefly describe the various evaluations and compare them to collections of data.

2 SURVEY OF EVALUATIONS

In this section, we present a survey of existing evaluations. This is divided into two parts. The first part is an overview of the ENDL99 evaluations, listing where they are deficient. In the second part, we discuss the rest of the evaluations and present a table of the "best" evaluations for each isotope, reaction and energy regime in each reaction.

ENDL99 [1] contains the point-wise representation of a variety of nuclear reactions, with emphasis on having kinematically complete reactions. Because of the specific uses of ENDL99 at Livermore, ENDL99 contains a different set of reactions and isotopes than the typical evaluated nuclear data library. Also because of the different needs, ENDL99 often contains less information than other databases. There are other minor differences in data format that we mention in our outline of the evaluation processing. In Table 1 we present a tally of what reactions are present in ENDL99 and what we perceive as the deficiencies in the tabulated cross sections.

Given that the ENDL99 evaluations are often incomplete, we must examine other evaluations to see if they can partially or wholly replace the inadequate ENDL99 evaluations. Choosing which evaluations (and why) are the "best" is nontrivial and complicated by several problems:

1. Inbreeding of evaluations. This is often the case with CENDL-2 and JEF-2.2.
2. Discontinuities in the evaluations where two different sub-evaluations are patched together. This is often the case with older evaluations.
3. Different physics at work in different regions leading to a "patchwork" appearance of the evaluations. This is most often the cause of the problem noted in item 2.
4. Lesser used isotopes get less attention (both from experimenters and evaluators).

We considered the evaluations in the BROND-2.2, ENDF/B-VI, JEF-2.2, JENDL-3.2 and CENDL-2 databases. In our examination of the individual evaluations, we considered two sources of information: the documentation that accompanies the evaluation files and combined plots of the evaluations and all available data for the reactions in question. In addition, we consulted some of the detailed reports for the evaluations when needed. The plots were generated with the help of the EXFOR+ENDF+ZVVIEW cross section retrieval tool on the IAEA Nuclear Data Service web site [7]. While this tool was extremely useful, it did have trouble rendering the high-energy portions of some JENDL-3.2 evaluations (particularly ^{234,235,236,238}U).

A summary of which evaluations we feel are the "best" is in Table 2. In this table, we broke the cross sections down into energy regimes corresponding to different physical processes; often the quality of an evaluation varies based on the processes involved. Detailed discussions of the evaluations for each isotope (when an evaluation exists) are in the appendix. In all cases, we discarded the BROND-2.2 evaluations because there was little to no documentation for the evaluations, making it difficult to judge them. Furthermore, the cross section plots in the resonance region are confusing, suggesting that there is a problem with the way the information is stored in the library.

3 REPLACING ENDL99 EVALUATIONS

In this section, we outline what and how we updated the ENDL99 database and related application libraries. We carried out the modifications to the application libraries (`ndf1`, `mcf1`, `mcf.pdb`) using the Computational Nuclear Physics group's latest tool, `FUDGE` (For Upgrading Data and Generating ENDL). The `FUDGE` system is a set of Python scripts that, as the name suggests, allows users to "fudge," or modify, the data in the ENDL database and then produces the associated binary libraries used by LLNL codes. `FUDGE` is currently in alpha testing stage with documentation available soon [8].

We generated the new libraries in a two step procedure. First, we created a new ^{232}U evaluation and installed it into the 175 group libraries. Second, we upgraded the fission and capture cross sections for ^{233}U to ^{238}U by inserting the resonance regions from either the JENDL-3.2 or the ENDF/B-VI evaluations.

The new ^{232}U evaluation is a hybrid: we took the cross sections from JENDL-3.2 and the outgoing particle distributions from the ^{234}U evaluation in ENDL99. At the time of the request for these evaluations, the ENDL translation of the JENDL-3.2 outgoing particle distributions was not available at the time of the request as the ENDF/B-VI to ENDL translation code is not complete. We then inserted the new ^{232}U evaluation into the ENDL99 binary libraries using the `FUDGE` code. We then reprocessed the ^{233}U, ^{234}U and ^{235}U isotopes so that the appropriate (n, xn) reactions on these targets will produce ^{232}U residuals in user codes.

The second step of the library creation was to add fission and capture resonances to the cross sections in the ENDL99 database. Again, we used `FUDGE` to create the hybrid capture and fission cross sections for ^{233}U to ^{238}U and insert them into the libraries. We used ENDL99 as a starting point and lifted fission and capture resonances from either JENDL-3.2 or ENDF/B-

Isotope	(n,γ)	(n,f)
^{231}U	N	N
^{232}U	N	N
^{233}U	Y	Y
^{234}U	Y‡	Y†
^{235}U	Y‡	Y
^{236}U	Y‡	Y‡
^{237}U	Y‡	Y‡
^{238}U	Y‡	Y†
^{239}U	Y‡	Y‡
^{240}U	Y‡	N

† Incomplete or nonexistent resonance region.
‡ Neutron resonances partially or wholly averaged out.

Table 1: Status of the U(n,γ) and U(n,f) evaluations in ENDL99.

		Thermal Region (approx. 0 - 1 eV)		Resolved Resonance Region (approx. 1 eV - 10 keV)		Unresolved Resonance Region (approx. 10 - 100 keV)		High Energy Region (above approx. 100 keV)	
Isotope	Reaction	Evaluation	EXFOR Data	Evaluation	EXFOR Data	Evaluation	EXFOR Data	Evaluation	EXFOR Data
231U	(n,f)	none	none	none	none	none	none	none	none
	(n,g)	none	none	none	none	none	none	none	none
232U	(n,f)		none		some		some		contridictory
	(n,g)	JENDL	none	JENDL	none	JENDL	none	JENDL	none
233U	(n,f)		lots		lots		lots		lots
	(n,g)		some		lots	JENDL	some	JENDL	little
234U	(n,f)	contridictory	none		lots		lots	ENDF/B or JENDL	lots
	(n,g)	ENDF/B or JENDL	none	ENDF/B or JENDL	averages	ENDF/B or JENDL	none	ENDF/B or JENDL	none
235U	(n,f)		lots		lots		lots		lots
	(n,g)		some		lots		lots		lots
236U	(n,f)		none		lots	JENDL or ENDF/B	none	JENDL or ENDF/B	contridictory
	(n,g)		lots		some		lots		contridictory
237U	(n,f)	JENDL	none	JENDL	some	JENDL	none	JENDL	some
	(n,g)	JENDL	none	JENDL	none	JENDL	none	JENDL	none
238U	(n,f)		none		some		lots		lots
	(n,g)		lots		lots		lots		lots
239U	(n,f)	none	none	none	none	none	none	none	none
	(n,g)	none	none	none	none	none	none	none	none
240U	(n,f)	none	none	none	none	none	none	none	none
	(n,g)	none	none	none	none	none	none	none	none

Legend:
Must do ourselves
Check as part of systematics
Steal existing evaluation

Table 2: Our recommendation for which evaluations to adopt in the event of inadequate ENDL99 evaluations.

VI and literally pasted them into the ENDL cross sections. We studied each set of cross sections to determine a pasting energy. Above the pasting energy, we left the existing ENDL99 evaluation alone. Below the pasting energy, we pasted in either the JENDL-3.2 or ENDF/B-VI cross sections. This way, the user may test the sensitivity of their application to the new high resolution resonance region without worrying about the rest of the cross section changing. A complete tally of our changes and the pasting energies are tabulated in Table 3.

4 PLANS FOR OTHER EVALUATIONS

Our use of existing evaluations to update ENDL99 is only an interim solution both because some of these evaluations need either repairs or a detailed check (^{237}U is such a case) and because we need to evaluate some of the reactions from scratch. Fortunately, we can capitalize on existing projects and N Division expertise.

We may break down the evaluations into roughly two regions of energy, the resolved resonance region ($\lesssim$ 10 keV) and the unresolved resonance and high-energy regions ($\gtrsim$ 10 keV). Below we detail our proposed schemes for producing evaluations in both regions and our plans for making uncertainty estimates.

Resolved resonance region

In the resonance region, the resonance widths are much smaller than the level spacing and the cross section is dominated by the resonances. If we know the resonances in either the (n,γ) or the (n,f)reactions, we can extract the resonances from the other because

$$\sigma_i \propto \frac{\Gamma_i}{\Gamma_f + \Gamma_\gamma + \Gamma_n}$$

so

$$\sigma_\gamma \sim \frac{\Gamma_\gamma}{\Gamma_f}\sigma_f$$

We would have to get the branching fractions, Γ_i, from systematics and fortunately the gamma ray strength functions are well understood.

Unfortunately, for the isotopes where there is no data, we have no idea of what the resonance structure is. If we do not need detailed resonance information, then we can produce the average cross section from systematics (in fact, this is already done for several isotopes in ENDL99). On the other hand, if we do need resonances then we must figure out whether we actually need the *correct* resonances. If so, then short of performing difficult and time consuming experiments, there is nothing we can do. If not, then there is a simple trick proposed by Ormand [10] that we can use to generate fake resonances.

To generate a fake resonance, we need the resonance width and energy. In most cases, the width is simple to calculate as the resonances are either s-wave or p-wave resonances. We may neglect higher ℓ resonances as the neutron penetrability drops as ℓ increases. To get the energy for a resonance, we can use systematics of the level spacings to manufacture a level density. From the level density, we generate a realistic level spacing distribution $S(E)$. This distribution will most likely be a Wigner distribution. Starting at some fixed energy, we then use $S(E)$ to generate the spacing between this energy and the i^{th} resonance: $E_i = E_0 + \sum_i S_i E_i$. Using this scheme we can manufacture a realistic, but fake, set of resonances for any isotope.

Unresolved resonance and high-energy regions

In the high-energy region (above several hundred keV), we may treat both fission and capture channels within the same calculation using traditional statistical reaction theory (a.k.a. Hauser-Feshbach theory). For such simulations, there are several parts which we must either find or mock-up from systematics of the mass region. These parts include various low energy level schemes for the compound nuclei, level densities for the compound nuclear system, fission barrier heights, optical model potentials, and transmission coefficients.

For the (n,f) reactions we are hampered due to the lack of predictability of the fission models in our reaction codes. Younes and Britt [9] have devised a method for estimating U(n,f) cross sections using systematics garnered from surrogate (t,pf) reactions on several isotopes. They are in the process of performing this analysis for a variety of isotopes of interest in the current work, namely ^{235,235m,237,239}U as well as several thorium and plutonium isotopes. This work will give us a crucial handle on the high energy (100 keV – 3 MeV) region of some U(n,f) cross sections.

In the unresolved resonance region, the neutron resonances are no longer distinguishable as the widths of the resonances are larger than the level spacing. The cross sections in this region are dominated by Ericson fluctuations, which fortunately we can model using one of a few straight-forward extensions of Hauser-Feshbach theory. Each of these extensions require only the transmission coefficients that we already will generate for the high-energy reaction cross sections.

Uncertainty estimates

Providing uncertainty estimates should be straightforward. However, the current ENDL database lacks the

isotope	evaluation used	pasting energy
232	JENDL-3.2	n/a
233	JENDL-3.2	20 keV
234	ENDF/B-VI	200 keV†
235	ENDF/B-VI	200 keV
236	JENDL-3.2	100 keV
237	JENDL-3.2	100 keV
238	ENDF/B-VI	200 keV‡

† The ENDF/B-VI and new ENDL evaluations have $\approx 5\%$ difference above the pasting energy.
‡ The ENDF/B-VI and new ENDL evaluations have $\approx 2 - 10\%$ difference above the pasting energy.

Table 3: Table of changes to the ENDL99 database. Below the pasting energy we replaced the existing ENDL99 fission and capture cross section with the evaluations in column two. Above the pasting energy, ENDL99 is unchanged.

capability for storing this information. No timetable for including this information is set either. Because of this, our uncertainty estimates will be presented as a simple table of the average uncertainty over an energy range for a particular cross section. For existing evaluations, we may just use the evaluated uncertainties in the same way we took the rest of the cross sections. For the new evaluations, producing uncertainties will take care and making these estimates may take up most of the time in preparing the new evaluations.

5 Conclusion

We have produced an updated version of the ENDL99 database that includes both higher quality fission and capture cross section evaluations for uranium isotopes with A=233-238 and a new evaluation for ^{232}U. These changes are particularly important in the resonance region, allowing the users of this database greater control over the accuracy of their calculations. These changes have been propagated into various application libraries for use on the Livermore computers. Our future efforts will entail producing evaluations for several understudied uranium isotopes and estimating the uncertainties on all of the updated evaluations.

Appendix: Overview of evaluations

^{232}U

Evaluations exist in the JENDL-3.2, ENDF/B-VI, and JEF-2.2 databases. The JEF-2.2 evaluation may be ignored since they adopted the ENDF/B-VI evaluation.

There is no way to judge the quality of the U(n,γ) evaluations as there are no U(n,γ) data in the EXFOR database. An examination of the evaluation comments reveals that ENDF/B-VI agrees better with recommended values of [11] for the thermal parameters, and both evaluations take the resolved resonance parameters from [11]. JENDL-3.2 keeps more high energy resonances than ENDF/B-VI in the region from 60-200 eV and JENDL-3.2 is a better fit the background fission cross section (i.e. the fission cross section with the resonances removed). At higher energies, JENDL-3.2 appears to track the fission data well. It also appears as though the U(n,γ) and U(n,f) files for ENDF/B-VI were switched in the plots. If this is the case, then JENDL-3.2 and ENDF/B-VI may be treated as interchangeable in the higher energy region ($>$ 50 keV). Given the slightly better treatment of the resonance region, we recommend using the JENDL-3.2 evaluation.

^{233}U

Owing to the interest in the thorium fuel cycle, it should be no surprise that this isotope is well studied. Indeed, evaluations exist in the JENDL-3.2, JEF-2.2, and ENDF/B-VI databases. We drop JEF-2.2 from consideration as it adopted the ENDF/B-VI evaluation.

We recommend the JENDL-3.2 evaluation. Only JENDL-3.2 uses a recent evaluation of the resonance parameters using the SAMMY code [12]. Furthermore, JENDL-3.2 uses the spline fit based U(n,f) evaluation of Kawano *et al.* [13]. This evaluation has noticeably smaller uncertainty than any other evaluation.

^{234}U

Only ENDF/B-VI, JENDL-3.2, and JEF-2.2 evaluations exist for this isotope and JEF-2.2 adopts the ENDF/B-VI evaluation entirely.

In the thermal region, there is not a lot of data to constrain either channel. An upper limit on the (n, f) cross section was found [11]. This coupled with measurements of the total and elastic cross sections allowed JENDL-3.2 and ENDF/B-VI to set the U(n, γ) cross section. However both evaluations choose to handle the fission channel limit differently.

Above the thermal region, all evaluations take their resonance parameters from the same work [14]. In the unresolved resonance region (from 20 keV-100 keV), the data exhibit a lot of scatter and it is difficult to decide which of the ENDF/B-VI and JENDL-3.2 U(n, f) evaluations is best, despite the large difference in the behavior of the evaluations (JENDL-3.2 is nearly constant while ENDF/B-VI evaluation attempts to track the detailed shape of the cross section). Above 100 keV, both ENDF/B-VI and JENDL-3.2 use the fission cross section of Ref. [15]

Since the two evaluations are equivalent outside of the thermal region, we recommend taking either one.

^{235}U

As this isotope is the most important uranium isotope for nuclear applications, it should be no surprise that not only are there plenty of data, but all of the evaluations more or less agree on the cross sections. The databases that include this isotope are ENDF/B-VI, JENDL-3.2, JEF-2.2, and CENDL-2. Both CENDL-2 and JEF-2.2 evaluations are simply adopted from ENDF/B-VI. We concentrate on the ENDF/B-VI and JENDL-3.2 evaluations.

In the resonance region, ENDF/B-VI's evaluation is clearly superior due to the fact that it uses the recent evaluation of Ref. [17] which performed a Bayesian extraction of the resonance parameters from both differential and integral data. JENDL-3.2 evaluation used an older version of this evaluation that ignored the integral data.

In the unresolved resonance region, ENDF/B-VI uses the evaluation of Ref. [18] and in the high energy region, the Hauser-Feshbach calculations of Ref. [19]. The recent JENDL-3.2 evaluation [13] agrees with the ENDF/B-VI evaluation even though JENDL-3.2 uses a completely different technique: a spline fit to the measured data. Both are in agreement with the earlier NIST Standards evaluation [16]. This agreement gives us confidence in the ENDF/B-VI evaluation.

Because the ENDF/B-VI evaluation is superior to the JENDL-3.2 evaluation in the resonance region and essentially equivalent to it at higher energy, we recommend the ENDF/B-VI evaluation.

^{236}U

Databases that include ^{236}U are ENDF/B-VI, JEF-2.2, and JENDL-3.2. We drop the JEF-2.2 evaluation from consideration as it uses a combination of old evaluations and the current ENDF/B-VI evaluation.

Outside of the resonance region, both the ENDF/B-VI and JENDL-3.2 U(n, γ) evaluations are of comparable quality owing to the large amount of data. For the U(n, f) evaluations, the situation is a little worse. At high energies (> 100 keV) there is plenty of data to constrain the evaluations. However, in the unresolved resonance region there is little to no data until one reaches the resonance region. As a result, the ENDF/B-VI evaluation contains a kink where the high energy part is matched on to an extrapolated average cross section from the resonance region. The JENDL-3.2 cross section is much better behaved in this region, but this did not show up in the plot (this indicates a problem with the IAEA plots as the cross section on the JENDL-3.2 web site is OK).

In the resonance region, both evaluations do an adequate job of reproducing the measured resonance structure in the U(n, f) data and they seem to have reapplied the resonance parameters to the U(n, γ) reaction. Both evaluations use the resonance parameters from the evaluation in Ref. [20].

In the thermal region, both evaluations used Ref. [11] as a guide for the thermal cross sections. As a result, both evaluations have identical (n, γ) cross sections. The evaluations differ in their fission cross sections with JENDL-3.2 agreeing better with the thermal cross section recommended by Ref. [11].

In the end, we recommend the JENDL-3.2 evaluation because it avoids the kinks in the unresolved resonance region even though elsewhere JENDL-3.2 and ENDF/B-VI are essentially equivalent.

^{237}U

Only three evaluations exist for this isotope: JENDL-3.2, JEF-2.2, and ENDF/B-VI. The ENDF/B-VI evaluation was adopted in JEF-2.2, so we may drop JEF-2.2 from consideration.

Between the ENDF/B-VI and JENDL-3.2 evaluations, neither seem to have much contact with the data and what data there is is scarce. We provisionally recommend using the JENDL-3.2 evaluation simply because it does not have a discontinuity where two different evaluations where patched together, as ENDF/B-VI does. We must re-evaluate the reactions for this isotope.

^{238}U

Because this isotope is the most common one in natural uranium, it is no surprise that it is well studied.

As a result, there are evaluations for this isotope in all of the databases: CENDL-2, JENDL-3.2, JEF-2.2, and ENDF/B-VI. The CENDL-2 evaluation is not well documented and does not appear to make sense below the unresolved resonance region. This is most likely the result of a misinterpretation of the data files, however given the lack of documentation, it is difficult to sort this problem out. As with many of the other evaluations, JEF-2.2 chose to adopt an existing evaluation, in this case that of JENDL-3.2. Thus, we will restrict our considerations to the JENDL-3.2 and ENDF/B-VI evaluations.

In the resolved resonance region, both evaluations rely on the evaluation of Moxon and Sowerby [21]. Above this region, ENDF/B-VI uses a combination of systematics and the GNASH calculations while JENDL-3.2 uses the same spline fitting procedure that it uses in its ^{233}U and ^{235}U evaluations. Amazingly, both evaluations are in excellent agreement with each other and the data and each has comparable uncertainty. Because both evaluations are of comparable quality, we could recommend either.

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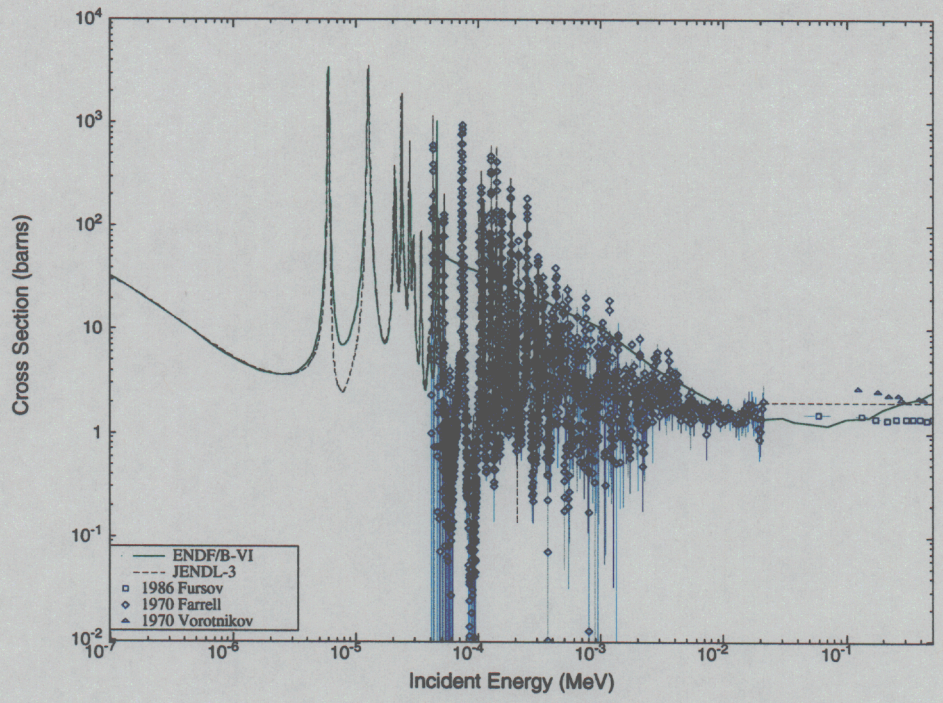

Figure 1: Status of the $^{232}\mathrm{U}(n,f)$ evaluations.

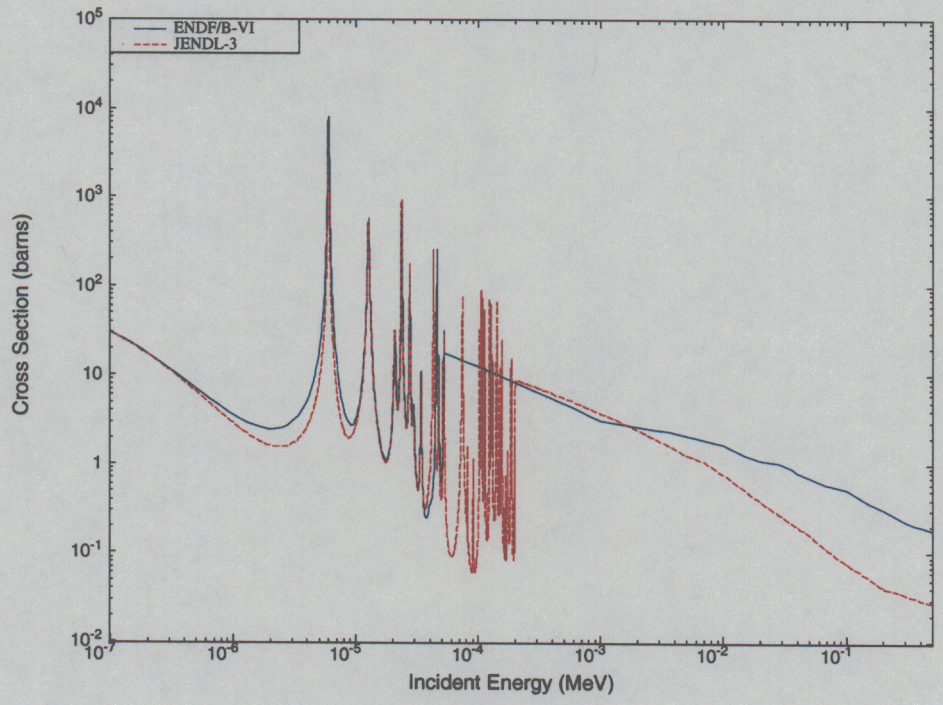

Figure 2: Status of $^{232}\mathrm{U}(n,\gamma)$ evaluations.

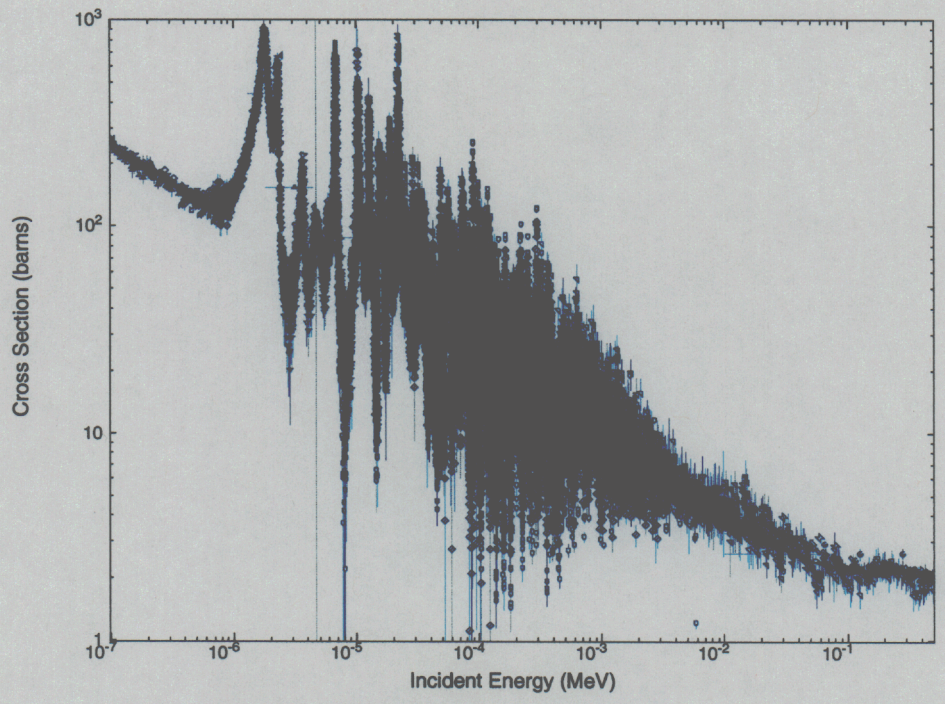

Figure 3: Status of the $^{233}\mathrm{U}(n,f)$ evaluations. Due to the large amount of data available, we have supressed the legend. In this plot, the ENDF/B-VI evaluation is in green and the JENDL-3.2 evaluation is in black.

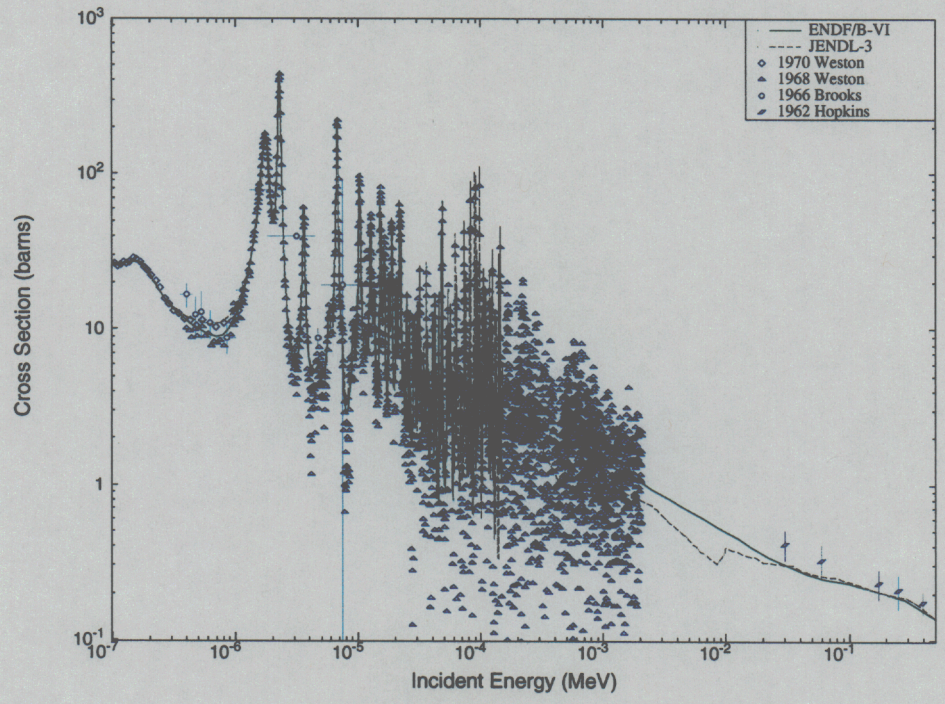

Figure 4: Status of $^{233}\mathrm{U}(n,\gamma)$ evaluations.

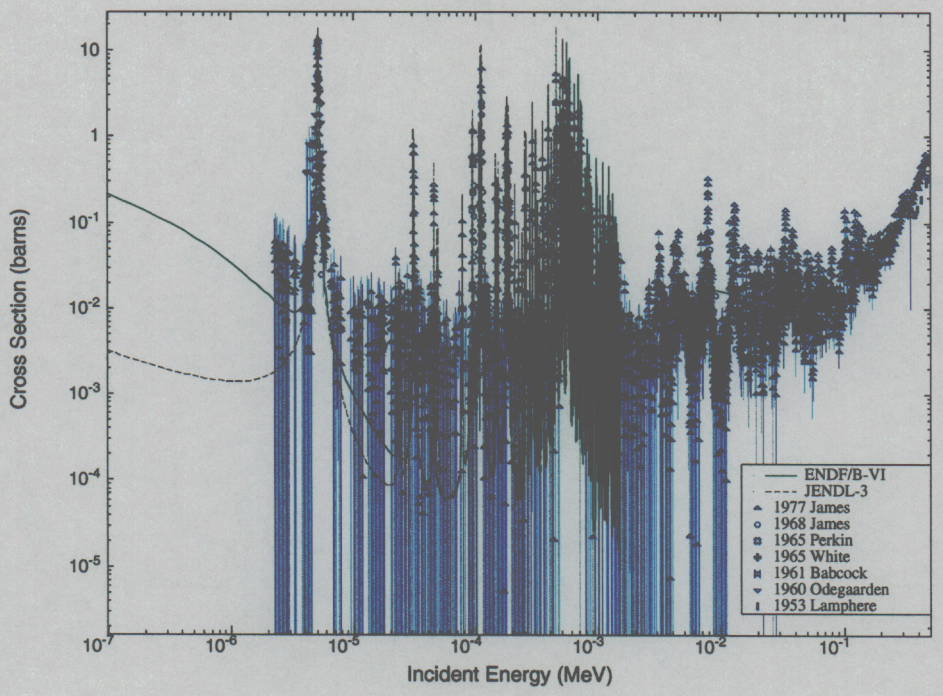

Figure 5: Status of the $^{234}\mathrm{U}(n,f)$ evaluations.

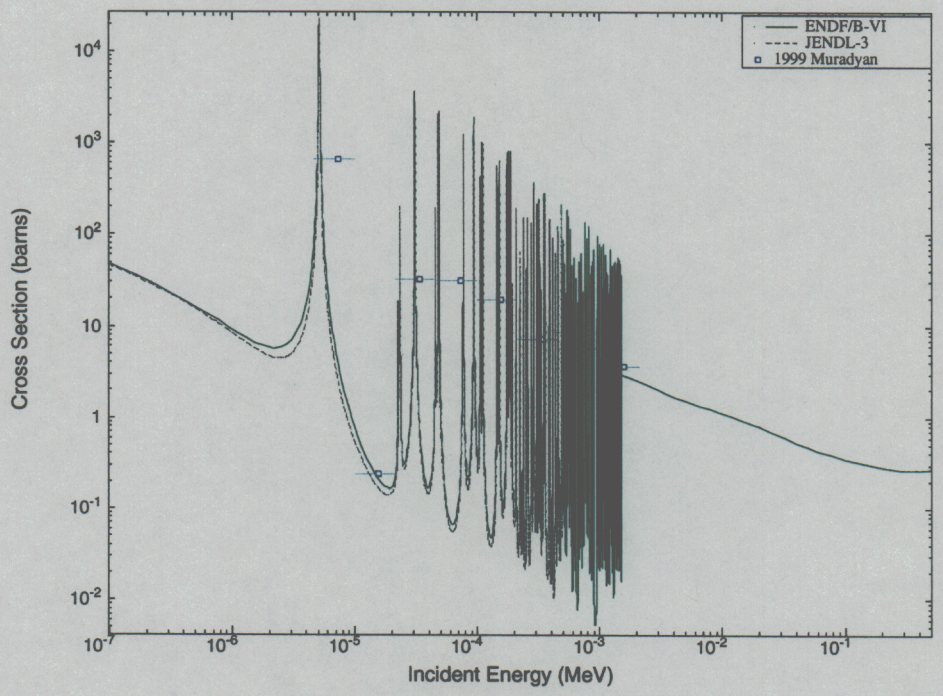

Figure 6: Status of $^{234}\mathrm{U}(n,\gamma)$ evaluations.

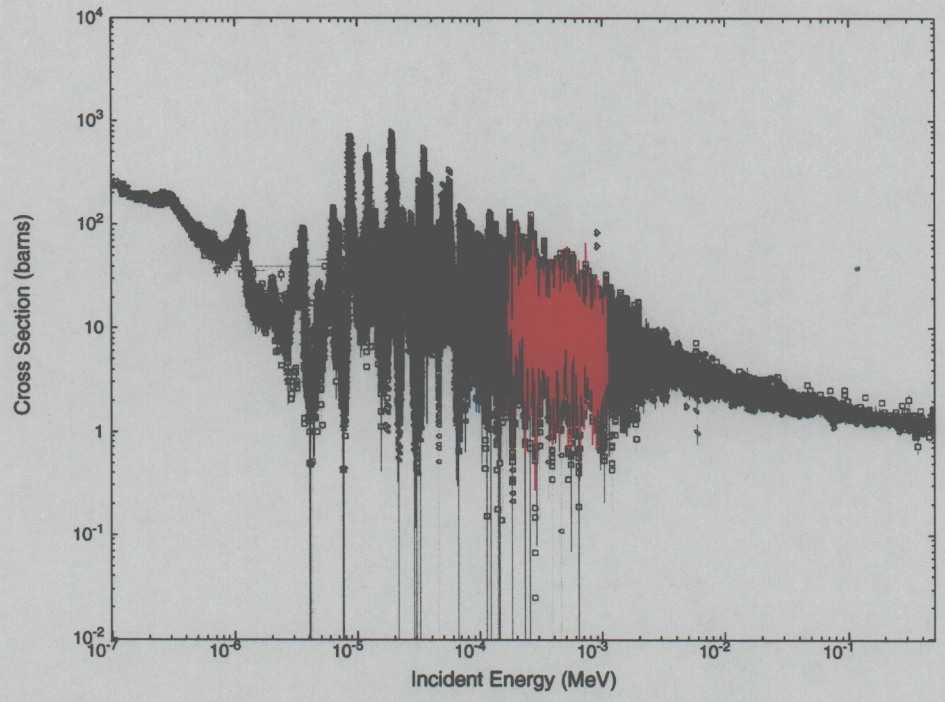

Figure 7: Status of the $^{235}\mathrm{U}(n,f)$ evaluations. Since there is so much data, we have supressed the legend. The magenta line to ENDF/B-VI and the cyan line to JENDL-3.2.

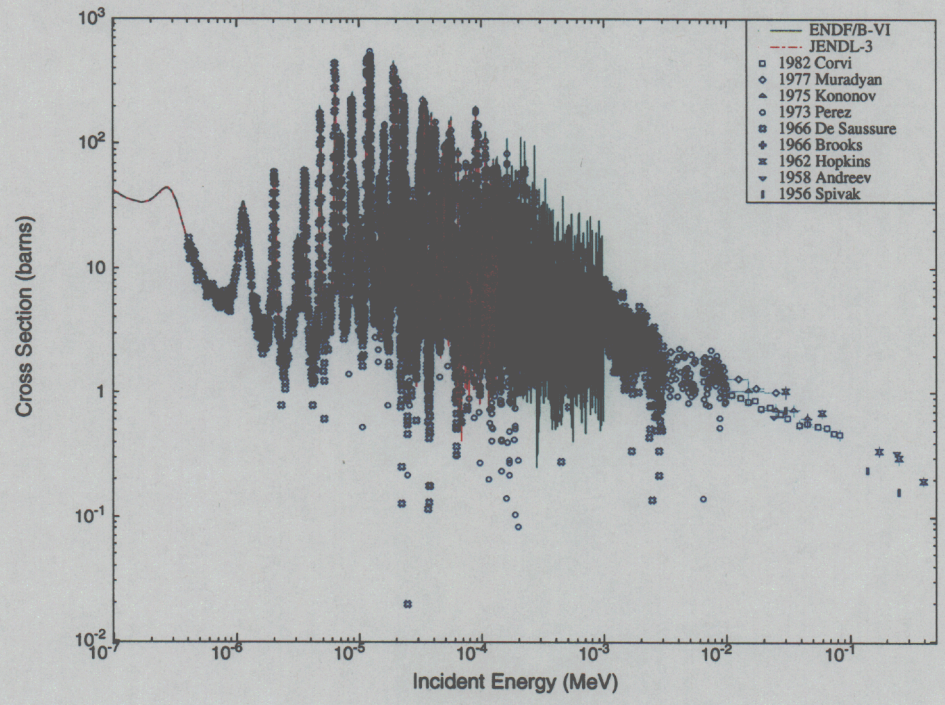

Figure 8: Status of $^{235}\mathrm{U}(n,\gamma)$ evaluations.

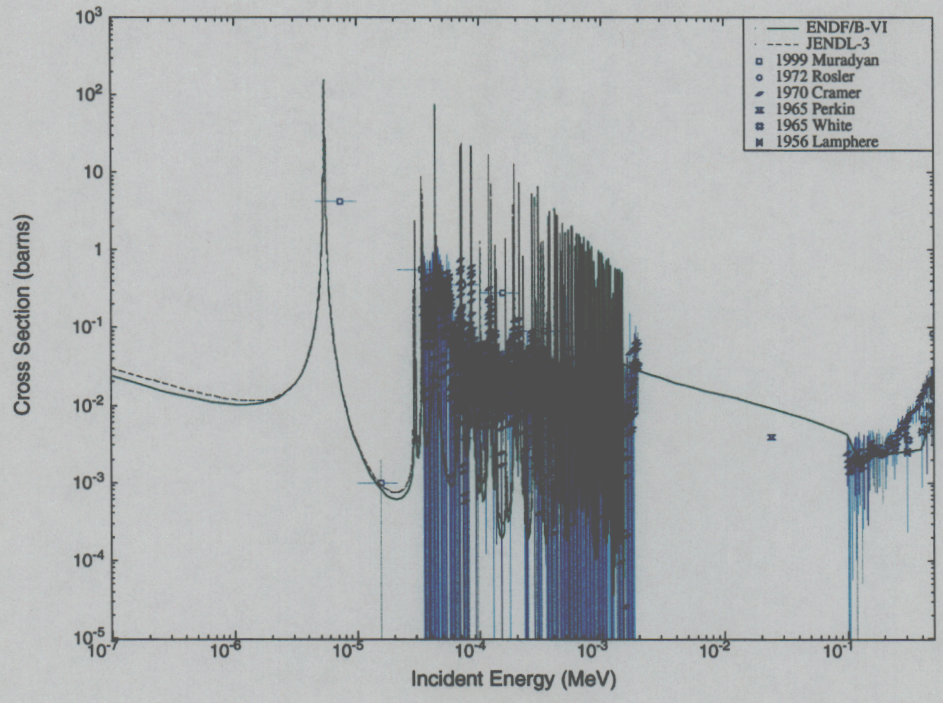

Figure 9: Status of the $^{236}\mathrm{U}(n,f)$ evaluations.

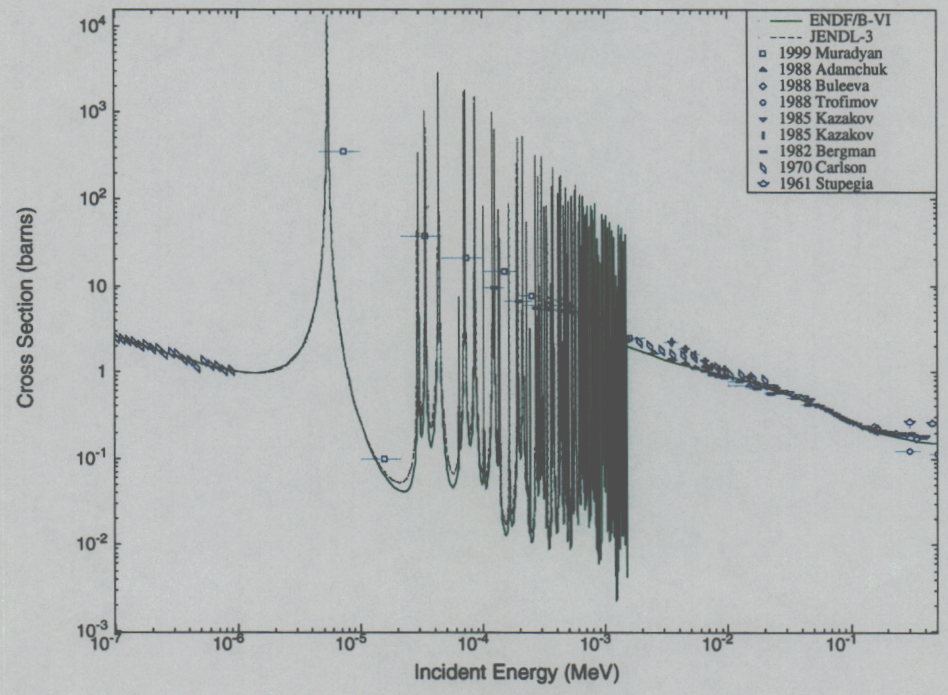

Figure 10: Status of $^{236}\mathrm{U}(n,\gamma)$ evaluations.

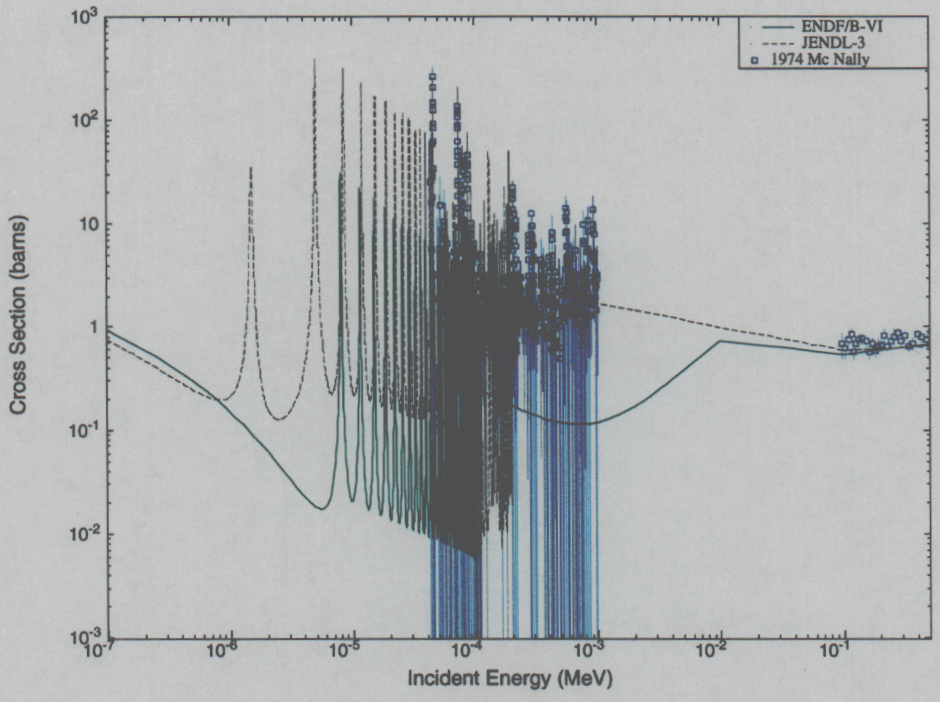

Figure 11: Status of the $^{237}\mathrm{U}(n, f)$ evaluations.

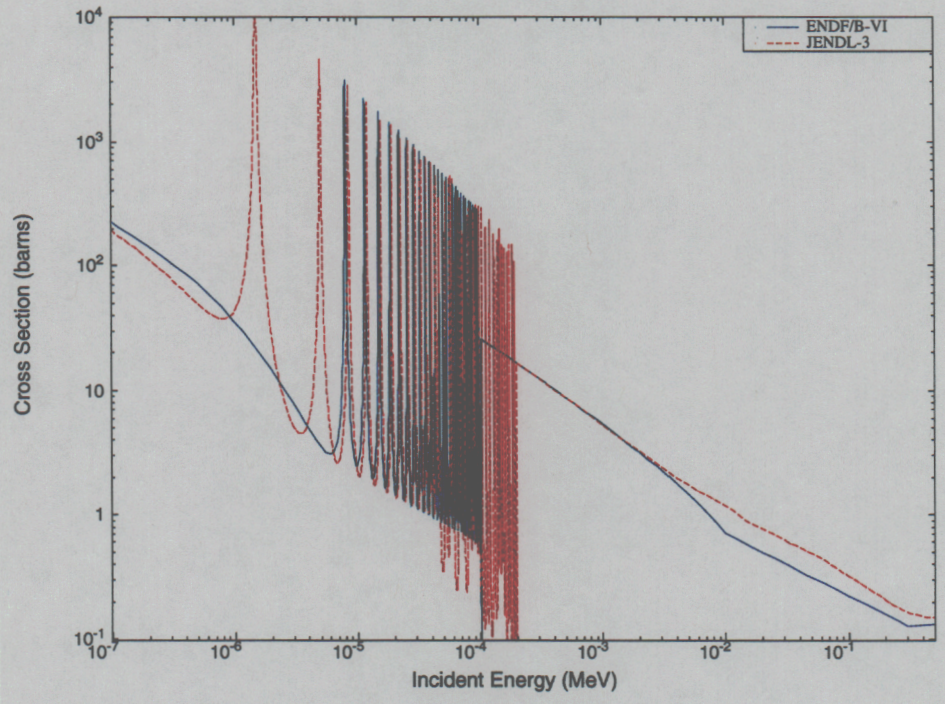

Figure 12: Status of $^{237}\mathrm{U}(n, \gamma)$ evaluations.

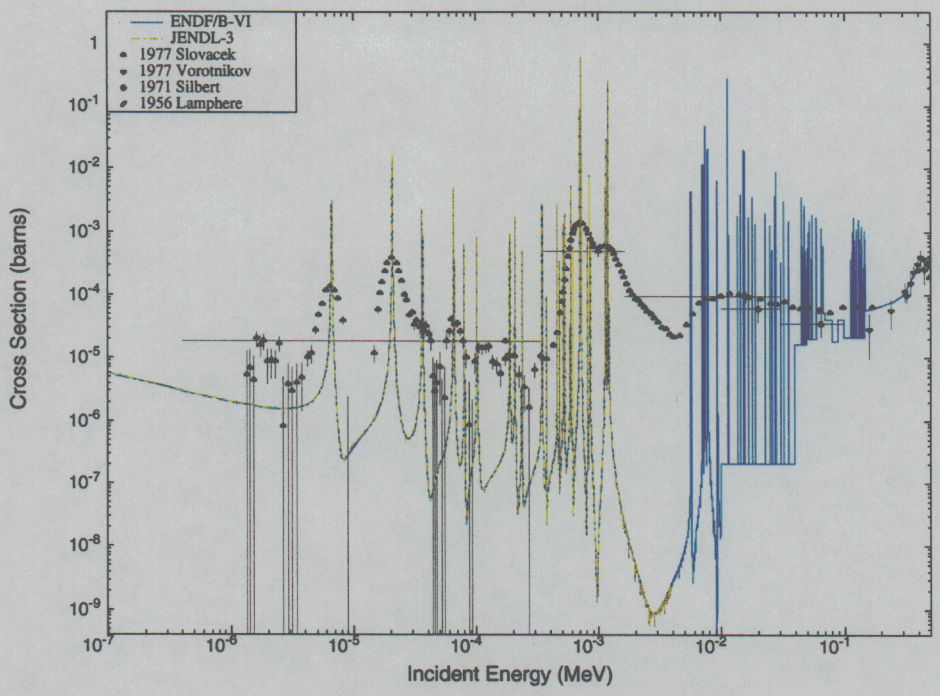

Figure 13: Status of the $^{238}\mathrm{U}(n, f)$ evaluations.

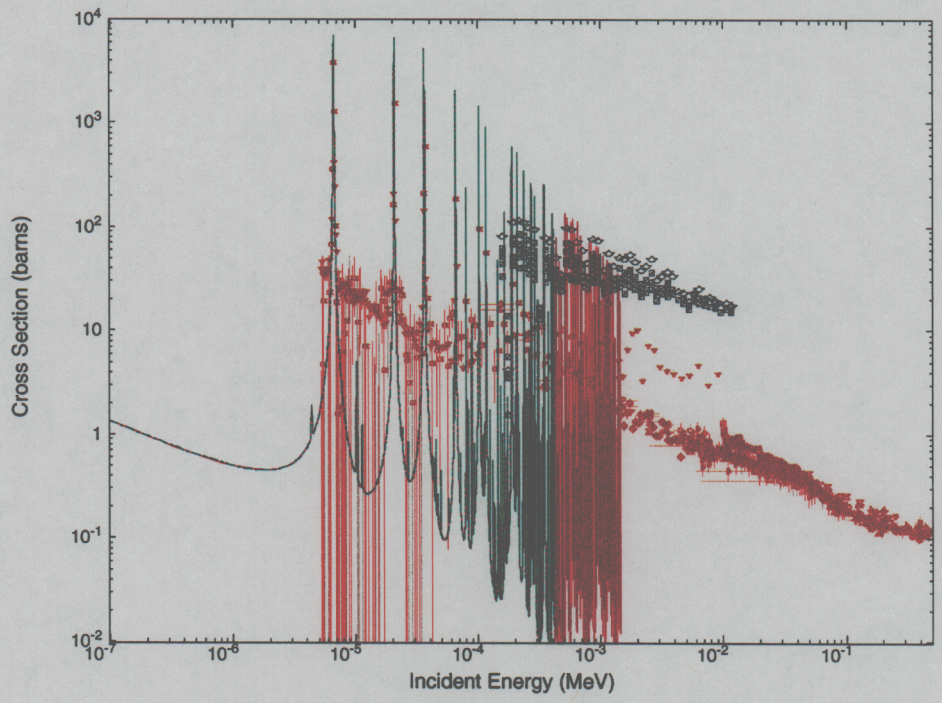

Figure 14: Status of $^{238}\mathrm{U}(n, \gamma)$ evaluations. Due to the large amount of data available, we have supressed the legend. In this plot, the ENDF/B-VI evaluation is in magenta and the JENDL-3.2 evaluation is in green.